High-z radio galaxies and the 'Youth-Redshift Degeneracy'

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Abstract. We discuss a unifying explanation for many 'trends with redshift' of radio galaxies which includes the relevance of their ages (time since their jet triggering event), and the marked dependence of their ages *on redshift* due to the selection effect of imposing a flux-limit. We briefly describe some important benefits which this 'youth-redshift degeneracy' brings.

1. Trends in COSMIC EPOCH or trends in SOURCE AGE?

With radio source ages of at most a few 10^8 years, the huge decrease in comoving space density of luminous radio-sources from redshift $z = 2$ to $z = 0$ (Longair 1966, Dunlop & Peacock 1990) is not due to a decline in luminosity of individual objects. However, it does not follow that one can ignore the luminosity evolution of the individual radio-sources and their ages in all studies of their 'cosmic evolution'.

Application of a flux-limit in any model of radio-galaxy evolution in which the luminosity (P) decreases with time means that all observable high-redshift radio-galaxies must be seen when the lobes are young ($< 10^7$ years old; see Figure 1). This mechanism (for details see Blundell & Rawlings 1999) is responsible for the highest-redshift members of any low-frequency survey of radio-sources (such as 3C) having significantly more powerful jets and being significantly younger than the more local members. This physical mechanism plays a crucial role in explaining 'trends with redshift', without invoking any intrinsic or strong environmental differences between the radio-galaxies seen at low-z and high-z; we discuss five such trends below.

(1) The linear size evolution which is observed in low-frequency flux-limited samples of classical double radio-sources (Kapahi et al. 1987, Barthel & Miley 1988, Blundell, Rawlings & Willott 1999) arises because the high–z sources are younger, hence tend to be shorter. Falle (1991) has shown that higher jet-powers (Q) increase the rate at which radio-source lengths (D) grow with time t. This positive dependence on jet-power of the rate at which the lobe-lengths grow contributes to the linear size evolution being as mild as it is (Blundell, Rawlings & Willott 1999).

(2) Barthel and Miley (1988) had suggested that higher redshift environments are denser and more inhomogeneous than at low redshift since they found increased distortion in the structures of their high-z sample of steep-spectrum quasars compared with their low-z sample. Young radio sources which have recently undergone a jet-triggering event [assumed to be a galaxy-galaxy merger

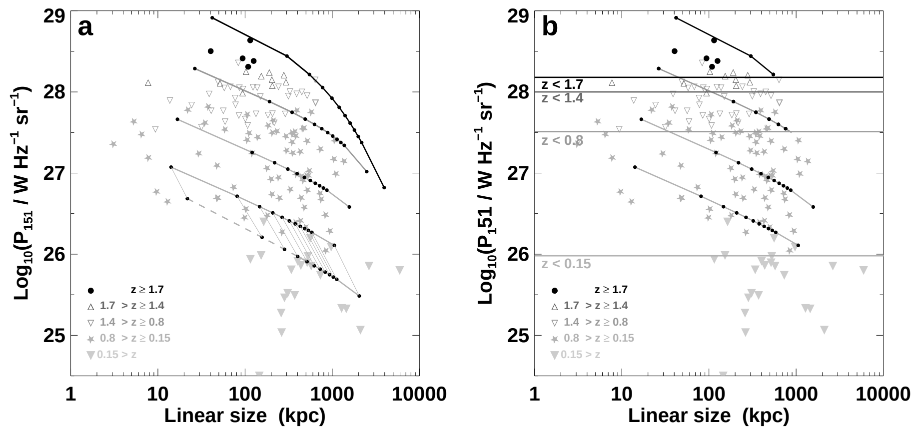

Figure 1. Overlaid on the 'P–D' plane for the 3C sample in **a** are model tracks tracing out the evolution of four example radio sources in luminosity and linear size with, from top to bottom, $Q = 5 \times 10^{39}$ W at $z = 2$, $Q = 1 \times 10^{39}$ W at $z = 0.8$, $Q = 2 \times 10^{38}$ W at $z = 0.5$ and $Q = 5 \times 10^{37}$ W at $z = 0.15$. The dashed line indicates how the lower track luminosity reduces by $<$ half an order of magnitude if the ambient density becomes an order of magnitude lower. In **b** the horizontal lines represent the luminosities at which the flux-limit of 12 Jy takes its effect at the different redshifts indicated. A combination of the dramatically declining luminosity-with-age of the high-Q sources, their scarcity in the local Universe, together with the harsh reality of the flux-limit means that very powerful sources with large linear sizes are rarely seen.

(Sanders et al. 1988)] may have the passage of their jets considerably more disrupted where there is a higher density and greater inhomogeneity in the ambient post-recent-merger environment. A general trend of denser inter-galactic environments at high-z cannot be inferred from their result.

(3) Where the alignment effect is caused by star-formation, it will be more easily triggered close in to the host galaxy or within the product of a recent merger than at distances further out sampled by the head of an expanding radio-source later in its lifetime. Where the alignment effect is caused by dust-scattered quasar light, the certain youthfulness of distant radio-galaxies alleviates the near discrepancy (De Young 1998) between radio-source ages and the time-scale for which dust grains can survive in the presence of shocks caused by the advancing radio-jets. The 'youth–redshift (YZ) degeneracy' is consistent with Best et al's (1996) finding that the smallest sources in a sample of $z \sim 1$ radio-galaxies (all with very similar luminosities) are those which are most aligned with optical emission. Indeed Best et al. suggest this as the explanation of their observation.

(4) Garrington & Conway (1991) have found a tendency for depolarisation to be higher in sources with higher z. Objects with higher z which are younger

will be in much more recently merged environments with the consequence that inhomogeneities in density or magnetic field will more readily depolarise the synchrotron radiation from the lobes. Moreover, higher-z sources being younger and somewhat shorter will be closer in to the centre of the potential well. The higher density in this region will enhance the observed depolarisation.

(5) Many of the highest–z radio-galaxies have gas masses comparable to gas-rich spiral galaxies (Dunlop et al 1994, Hughes et al 1998) and inferred star-formation rates which, in the local Universe, are rivalled only by galaxy-galaxy mergers like Arp 220 (Genzel et al 1998). If high-z objects are being viewed during a similar merging of sub-components, the associated star formation could be responsible for a significant fraction of the stellar mass in the remnant galaxy. Since the high-z radio-galaxies, those which have been detected by Hughes et al (1988) using SCUBA, are necessarily young ($< 10^7$ years, see Fig. 1), and since the whole merger must take a few dynamical crossing times, or 10^{8-9} years, the implication is that the event which triggered the jet-producing central engine is synchronised with massive star formation in a gas-rich system, perhaps as material streams towards the minimum of the gravitational potential well of the merging system.

The YZ degeneracy may help explain why few lower-z radio-galaxies show similarly large (rest-frame) far-infrared luminosities compared to the high-z population: they are being observed significantly longer after the jet-triggering event.

2. The elusiveness of cosmic parameters

A variant on Fig. 1 also includes the location on the P–D plane of the most extreme redshift ($z > 3$) radio galaxies known. Such a figure may be found in our recent letter to *Nature* (Blundell & Rawlings 1999). When these are plotted for different cosmological models, significant though subtle differences emerge for the high-z sources which illustrate the difficulty of distinguishing between different underlying cosmic geometries when more dramatic influences such as the YZ-degeneracy, and variations in source environments, are at work. In rough order of importance to the distribution of sources on the P–D plane, we have:

1. What is the finding frequency of the survey in the rest-frame of the source? (see Blundell, Rawlings & Willott [*astro-ph/9907418*])
2. What is the flux-limit? This excludes faint/old objects at high redshift.
3. What is Q, the jet-power?
4. What is the ambient density into which the radio-source is expanding?
5. What density profile is the radio-source expanding into?
6. What is the cosmic geometry?

The use of double radio sources as 'standardizable' rods (e.g. Daly 1994) is beyond reach.

3. The benefits of the YZ degeneracy

Since extreme-z radio galaxies are young, all with similar Q, they deliver the fine time-resolution required for the solution of problems which it may be difficult to study with objects like optically-selected quasars, whose ages are indeterminate: examination of the environments of distant radio galaxies provides a snapshot of the host galaxy evolutionary status just after the jet-triggering event.

At redshift ~ 4 we observe radio galaxies ~ 1 Gyr after the Big Bang and in environments which saw a jet-triggering event no earlier than 10^7 years prior to that. This time-step is over an order of magnitude smaller than the dynamical crossing time of a massive galaxy, and 2 orders of magnitude smaller than the age of the Universe at the epochs probed, giving fine time-resolution essential to any study of triggering (and hence merging) rates at early cosmic epochs.

The YZ-degeneracy is unavoidable, and implies a wide and increasingly ill-defined gulf between the 'luminosity function' and the 'birth function' of radio-galaxies. The luminosity function is a super-set of the radio-sources which make it above the various flux-limits. The 'birth function' measures the trigger rates of radio galaxies. We have carefully developed a model for radio-source evolution which for the first time in radio-source modelling incorporates the role played by the hotspots. This, together with a proper treatment for the interception of radio galaxies born at successively lower z with our light-cone, enables us to perform Monte-Carlo simulations to constrain the birth-function of radio galaxies out to high-z (Blundell, Rawlings & Willott, in prep).

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